Shape recovery using parametric models

Proposal to the Slovenian Ministry of Research and Technology

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12. November, 1990

Chief investigator:
Doc. dr. Franc Solina

Dean of Faculty of EE & CS:
Prof. dr. Baldomir Zajc

Principal investigator

Franc Solina, Ph.D., assistant professor of computer science

Other investigators

Aleš Jaklič, B.S.,
graduate student in computer science at University of Ljubljana (visiting University of Pennsylvania from June to December 1990).

Aleš Leonardis, B.S.,
graduate student in computer science at University of Ljubljana, (currently on leave at University of Pennsylvania from September 1988 to May 1991).

Number of new graduate student (young investigators) on the project

Two.

Collaborating investigators from abroad

Prof. Dr. Ruzena Bajcsy, Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia, PA 19104, USA.

Franc Solina and Ruzena Bajcsy submitted a joint project entitled *Image Segmentation with Parametric Part Models* to the National Science Foundation through the US-Yugoslav Joint Board Program.

Duration of project

Three years

Curriculum Vitae of Franc Solina

Education:

1987 University of Pennsylvania, Philadelphia, Pennsylvania, USA
Ph.D. in Computer and Information Science

1982 University of Ljubljana, Yugoslavia
M.S. in Electrical Engineering

1979 University of Ljubljana, Yugoslavia
Dipl. Ing. degree in Electrical Engineering

Experience:

Sept. 1988 – *Assistant Professor*, University of Ljubljana
Assignement in Department of computer and information science, Faculty of electrical engineering and computer science. Teaching courses in robotic sensors, software engineering, project management and introductory computer science.

1983–1988 *Graduate student and postdoctoral fellow*, University of Pennsylvania
Research in computer vision in General Robotics and Active Sensory Perception Laboratory.

1979–1982 *Research Assistant*, University of Ljubljana.

Personal:
Born 31. July, 1955 in Celje, Slovenia.

Journal publications

[1] Franc Solina and Ruzena Bajcsy. Recovery of mail piece shape from range images using 3-D deformable models. *International Journal of Research & Engineering, Postal Applications*, Inaugural Issue:125–131, 1989.

[2] Franc Solina and Ruzena Bajcsy. Recovery of parametric models from range images: The case for superquadrics with global deformations. *IEEE Transactions on Pattern Analysis and Machine Intelligence*, PAMI-12(2):131–147, 1990.

Book chapters

[1] Ruzena Bajcsy, Franc Solina, and Alok Gupta. Segmentation versus object representation—are they separable? In Ramesh C. Jain and Anil K. Jain, editors, *Analysis and Interpretation of Range Images.* Springer, New York, 1990.

Invited lectures/papers

Shape recovery from range images, Intelligent Machine Principles Division, Sandia National Laboratories, Albuquerque, New Mexico 87185, April, 1988.

Shape recovery from range images, Bell Laboratories, New Jersey, June, 1988.

Recovery of deformable part models—or how to model bananas and other assorted fruits, 41st Annual Conference Society for Imaging Science and Technology (SPSE) Arlington, VA, 1988.

Range image interpretation using superquadrics, 1988 Annual Metting of the Northeast Artificial Intelligence Consortium, Blue Mountain Lake, N.Y., 1988.

Interpretation of range images, Fifth Copenhagen Workshop in Computational Vision, Institute of Datology, University of Copenhagen, September, 1988.

Conference proceedings

[1] Krunoslav Turkulin, Ludvik Gyergyek, Marjan Vezjak, Franc Solina, Vojko Valenčič, and Slobodan Ribarić. Computer analysis of exercise electrocardiograms. In *Proceedings International Symposium on Non-Invasive Methods in Cardiology*, pages 25–33, Dubrovnik, 1980.

[2] France Mihelič, Marjan Vezjak, Ludvik Gyergyek, Viljem Rutar, Aleksander Janežič, Franc Solina, and Franc Jager. Determination of torsion and curvature of spatial qrs loop. In *Proceedings Fourth World Conference on Medical Informatics*, pages 689–692, Amsterdam, 1983.

[3] Damjan Zazula, Krunoslav Turkulin, Ludvik Gyergyek, Marjan Vezjak, Franc Jager, and Franc Solina. An 8-bit microcomputer for on-line analysis of exercise electrocardiograms. In *Proceedings Computers in Cardiology Conference*, pages 415–418, Aachen, 1983. IEEE.

[4] Franc Solina and Ruzena Bajcsy. Modeling of mail pieces with superquadrics. In *Proceedings Second USPS Advanced Technology Conference*, pages 472–481, Washington, DC, 1986.

[5] Franc Solina and Ruzena Bajcsy. Shape and function. In *SPIE Proceedings Vol. 726: Intelligent Robots and Computer Vision*, pages 284–290, Cambridge, MA, 1986.

[6] Ruzena Bajcsy and Franc Solina. Three dimensional shape representation revisited. In *Proceedings First International Computer Vision Conference*, pages 231–241, London, England, 1987. IEEE.

[7] Franc Solina and Ruzena Bajcsy. Range image interpretation of mail pieces with superquadrics. In *Proceedings AAAI-87*, pages 733–737, Seattle, 1987.

[8] Marjan Vezjak, Ludvik Gyergyek, Franc Solina, Viljem Rutar, France Mihelič, Nikola Pavešić, and Aleksander Janežič. Left ventricular hypertrophy diagnosis by means of vectorcardiographic parameters. In *Proceedings 1987 DECUS Europe Symposium*, pages 548–551, Rome, Italy, September 1987.

[9] Franc Solina and Ruzena Bajcsy. Shape recovery of mail pieces using deformable models. In *Proceedings USPS Third Advanced Technology Conference*, Washington, DC, 1988.

[10] Franc Solina and Ruzena Bajcsy. Recovery of deformable part models—or how to model bananas and other assorted fruits. In *Preprint book of 41st Annual Conference*, pages 31–34, Arlington, VA, 1988. Society for Imaging Science and Technology (SPSE). Invited paper.

[11] Franc Solina. Range image interpretation using superquadrics. Presentations from the 1988 Annual Metting WR-9901-1, Northeast Artificial Intelligence Consortium, Blue Mountain Lake, N.Y., 1988.

[12] Franc Solina. Uporaba umetnega vida v robotiki—pregled metod. In *Zbornik radova JU-ROB'89*, Opatija, 1989.

[13] Franc Solina. Rekonstrukcija oblik s kompaktnimi prostorskimi modeli. In *Zbornik radova XXXIII. Jugoslovanska konferenca ETAN*, pages XIII.43–50, Novi Sad, 1989.

Advisor

Ph.D. thesis: Tatjana Zrimec,
Senior theses: Andreja Balon, Georg Pollak, Matej Mlakar,
Graduate students: Aleš Jaklič, Matej Mlakar, Valentina Filova.

Professional affiliations

- American Association for Artificial Intelligence,
- Institute of Electrical and Electronics Engineers,
- International Association for Pattern Recognition.

Participation in projects

- Participated in several projects for the Slovenian Research Council while a graduate student at University of Ljubljana,
- Worked on interpretation of range images of mail pieces under a US Postal Service contract at University of Pennsylvania,
- Participated and gave talks at DARPA Image Understanding/Strategic Computing review meetings (Autonomous Land Vehicle Project).

International cooperation

- Ongoing cooperation with Ruzena Bajcsy, director of GRASP Laboratory at University of Pennsylvania. A three year joint project was submitted to NSF through the USA-Yugoslav program,
- regular contacts and exchange of research results with several researchers in USA and Europe,
- the superquadrics recovery program developed as a part of Solina's Ph.D. research is used by several vision and robotic research groups, among them the Mars Rover project team at Carnegie Mellon University, Pittsburgh, PA.

Awards

- B. Kidrič prize for innovations 1982,
- Fulbright travel fellowship 1983,
- International Research and Exchange Board research fellowship 1983/84,
- Morris and Dorothy Rubinoff award 1988 for research that could lead to innovative use of computers.

Curriculum Vitae of Ruzena Bajcsy

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School of Engineering and Applied Science
University of Pennsylvania
Philadelphia, PA 19104
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Position: Professor

Primary Appointment:	Computer and Information Science Department
Secondary Appointment:	Anatomy Department, School of Medicine
Graduate Group:	Neuroscience Department, School of Medicine

Chair, Computer and Information Science Department

Educational Background

1957	Slovak Technical University	M.S.E.E.
1967	Slovak Technical University	Ph.D.
1972	Stanford University	Ph.D.

Professional Experience

1957-1962	Research engineer, Electro-acoustic Department, Tesla, Bratislava, Czechoslovakia.
1962-1964	Maintenance engineer, (for computer URAL 2), Computation Center, Slovak Technical University, Bratislava, Czechoslovakia.

Teaching and Research Experience

1956-1957	Instructor, Department of Mathematics, Slovak Technical University, Bratislava, Czechoslovakia.
1964-1967	Assistant Professor, Department of Computer Science, Slovak Technical University, Bratislava, Czechoslovakia.
1967-1968	Research Assistant, Artificial Intelligence Project, Stanford University, Stanford, California.
1968-1969	Teaching Assistant, Department of Computer Science, Stanford University, Stanford, California.
1972-1977	Assistant Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia.
1977-1984	Associate Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia.
1984-	Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia.
1985-	Chair, Department of Computer and Information Science, School of Engineering and Applied Science, University of Pennsylvania

Awards

- Research Fellowship, Penza, Soviet Union, October 1962–January 1963.
- Graduate Fellowship for study at Stanford University, October 1967–January 1972.

- Research Fellowship Pattern Recognition Group, CERN, Geneva, January–May 1975. (Because of my immigration status, I was not able to accept it at that time).
- Visiting scientist at INRIA-FRANCE, January–June 1979.
- Visiting Professor, Datalogisk Institut of the University of Copenhagen, April 15–June 30, 1984.
- Visiting Professor, Centro "E. Piaggio", University of Pisa, Pisa, Italy, March 1988.
- Visiting Professor, Datalogisk Institut of the University of Copenhagen, August 1988.
- Forsythe Lecturer, Department of Computer Science, Stanford University, February 1989.

Publications

1. "A Report on Teaching Machines", *Sdelovaci Technika*, 1966 (In Czechoslovakia).
2. "Linear Learning Models", *Kybernetika*, **2**, 64-67, 1966 (In Czechoslovakia).
3. "Learning Models in Random Environments", *Kybernetika*, 3, 1967 (In Czechoslovakia).
4. "Identification of the Effect of Maintenance on the Reliability of Technical Systems", *Elektrotechnicky Casopis*, 19, 265-274, 1968 (In Czechoslovakia).
5. "Computer Identification of Visual Surfaces", *Computer Graphics and Image Processing*, 113-130, February 1973.
6. "Image Filtering a Context Dependent Process", *IEEE Transactions on Circuits and Systems*, May 1975, (Co-author: M. Tavakoli).
7. "Computer Recognition of Roads from Satellite Pictures", *IEEE Transactions on Systems, Machines and Cybernetics*, September 1976 (Co-author: M. Tavakoli).
8. "Monocular Depth Cues–A Computer Model", *Computer Graphics and Image Processing*, 52-67, May 1976 (Co-author: L. I. Lieberman).
9. "A Structured World Model in Flexible Recognition of 2-D Patterns", *Pattern Recognition*,**9**, No. 1, January 1977.
10. "Three-Dimensional Representations for Computer Graphics and Computer Vision", *Computer Graphics*, **12**, No. 3, August 1978 (Co-author: N. Badler).
11. "Computer Analysis and Description of Pottery Sherd Patterns", *International Journal on Policy Analysis and Information Systems*, **3**, 1, July 6 1979 (Co-author: S. Scidmore).
12. "Generalized Cylinders from Local Aggregation of Sections", *Pattern Recognition*, **12**, 1, 1980, (Co-authors: B. Soroka, R. Andersson).
13. "Computer Assisted Analysis of Tomographic Images of the Brain", (co-authors: T. Adair, M. Reivich, P. Karp, and A. Stein), *Journal of Computer Assisted Tomography*, **5**, 6, 029-932, 1981.
14. "Packing Volumes by Spheres", *IEEE Transactions on PAMI*, **5**, 1, 111-116, 1983 (Co-author: R. Mohr).
15. "A Computerized System for Elastic Matching of Deformed Radiographic Images to Idealized Atlas Images", *JCAT*, February 1983 (Co-authors: R. Lieberson and M. Reivich).
16. "Active Touch and Robot Perception," *Cognition and Brain Theory*, 1984, 7 (2) pp. 199-216 (Co-author: K. Goldberg).

17. "Acquiring 3-D Spatial Data of a Real Object", *Computer Graphics and Image Processing* 28, 1984, pp. 126-133 (Co-authors: C.K. Wu and D.Q. Wang).

18. "Visual and Conceptual Hierarchy: A Paradigm for Studies of Automated Generation of Recognition Strategies," *IEEE Transactions On Pattern Analysis and Machine Intelligence*, pp. 319-325, 1984, (Co-author: Rosenthal, D.).

19. "Multi-resolution elastic matching", Accepted for Publication, CVGIP, 1988, (Co-author: Kovacic S.)

20. "Active Perception", Proceedings of the IEEE on Computer Vision, August 1988.

21. Preliminary Clinical Evaluation of Multi-Resolution Elastic Matching Software,(Co-authors: Robert Dann, John Hoford, Stane Kovacic, Martin Reivich), *Journal of Computer Assisted Tomography*, 1989.

22. "Recovery of Mail Piece Shape from Range Images Using 3-D Deformable Models", (Co-author: Franc Solina), *International Journal of Postal Research and Engineering*, 1989.

23. "Recovery of parametric models from range images: the case for superquadrics with global deformations", Accepted for publication in *IEEE Transactions on PAMI* (Co-author: F. Solina).

Chapters in Books

1. "A Partially Ordered World Model and Natural Outdoor Scenes", in *Machine Vision* (ed: E. Riseman and D. Hanson), Addison-Wesley, 1978

2. "Visual and Conceptual Focus of Attention," *Structured Computer Vision* (edited by A. Klinger and S. Tanimoto, Academic Press, 1980) (Co-author: D. Rosenthal).

3. "Three-Dimensional Scene Analysis", in *Pattern Recognition Theory and Applications*, (Proceedings of NATO ASI, St. Anne's College, Oxford, 29 March-10 April 1981), D. Reidel Publishing Co., eds.: J. Kittler, K. S. Fu and L. Pau.

4. "Computerized Anatomy Atlas", in *Pattern Recognition Theory and Applications*, (Proceedings of NATO ASI, St. Anne's College, Oxford, 29 March-10 April 1981), D. Reidel Publishing Co., eds.: J. Kittler, K. S. Fu and L. Pau, (Co-authors: P. Karp and A. Stein).

5. "Segmentation of Tomographic Images", in *Biomedical Image Processing* (Proceedings of the United States-France Seminar, May 1980), eds.: J. Sklansky and J. C. Bisconte, Springer-Verlag, New York, 1981.

6. "Integrating Vision and Touch for Robotics Applications", in:*Trends and Applications of AI in Business* (ed. W. Reitman), Ablex Publ. Co, 1984.

7. "Shape from Touch", in *Advances in Automation and Robotics, Theory and Application*, (ed.: G. Saridis) Vol. 1, Summer 1984, JAI Press Inc.

8. "Parallels Between Vision and Touch", in *Vision, Brain and Cooperative Computation* (ed.: M. A. Arbib and A. R. Hanson), 1984.

9. "Three-Dimensional Analysis and Display of Medical Images", in *Positron Emission Tomography* (eds.: M. Reivich and Abass Alavi), Alan R. Liss, Inc., Scientific, Medical and Scholarly Publ., N.Y., 1984.

10. "What can we learn from one finger experiments?" In M. Brady and R. Paul (Eds.), *The First International Symposium on Robotics Research*. Cambridge, MA: The MIT Press, 1984.

11. "Integrating Vision and Touch for Grasping of an Object", in *Computer-Based Automation* (ed.: Julius Tou), Plenum Publishing Corp., 1985, pp. 387-398.

12. "Converging Disparate Sensory Data," Proceedings of the 2nd International Symposium on Robotics Research, (ed. Hanafusa and Inoue) MIT Press, 1985, pp. 81-87, (Co-author: P. Allen).

13. "Multisensor Integration", *Encyclopedia of Artificial Intelligence*, John Wiley & Sons, Publ., 1986.

14. "Tactile Information Processing", *Pyramidal Systems for Computer Vision*, V. Cantoni and S. Levialdi, NATO ASI Series, Series F: Computer and Systems Sciences, Vol. 25, Springer Verlag, 1986.

15. "Two Sensors Are Better Than One: Example of Integration of Vision and Touch", *Robotics Research: the Third International Symposium*, (eds: O. Faugeras and G. Giralt), MIT Press, 1986, pp. 59-64.

16. "Models of Errors and Mistakes in Machine Perception - Part 1. First Results for Computer Vision Range Measurements", NATO ASI Series, Series F: Computer and Systems Sciences, Vol. 43, Springer Verlag, 1987 (Co-authors: Eric Krotkov and Max Mintz).

17. "Perception via Manipulation", Proceedings of the Fourth International Symposium of Robotics Research, (edited by R. Bolles and B. Roth), MIT Press, August 1987.

18. "Segmentation versus object representation – are they separable?" (Co-authors: Franc Solina and Alok Gupta), Presented at the Range Image Understanding Workshop, March 21-23, 1988. (To appear as a Book Chapter: ed. Ramesh Jain, Springer Verlag).

Conference Proceedings

More then 70 papers presented at International Conferences.

Editorial Boards

- Co-editor of special issue of *Computer Vision, Graphics, and Image Processing*, 1980.
- Associate Editor of *Trans. of IEEE on Pattern Analysis and Machine Intelligence*, since 1981.
- Editor of the *Newsletter of the International Association for Pattern Recognition* 1981-1984.
- Associate Editor of the *Computer Graphics and Image Processing Journal* since 1983.
- Associate Editor of the *Pattern Recognition Letters* since 1983.
- Associate Editor of *Journal of Robotic Systems* since 1983.
- Associate Editor of *Journal of Computer Vision* since 1986.
- Area Editor of *CVGIP: Image Understanding* since 1989.

Conference Chairs

- Co-chairman of PRIP–Chicago, 1979.
- Publicity chairman of the International Pattern Recognition Conference, 1980.
- Session chairman on the International Pattern Recognition Conference, Munich, 1980 and 1982.
- Invited session chair, "Edge Detection", IEEE Workshop on Computer Vision, Miami, Florida, November 30 - December 2, 1987.
- Chairman, Review Committee for Undergraduate Programs in Computer Science, Loyola University, March 1988

- Chairman, Review Committee for Undergraduate Programs in Computer Science, Tulane University, March 1988
- Co-Chair, Second International Conference Computer Vision, December 5-8, Tarpon Springs, Florida, 1988.
- Invited session chair, "Edge Detection," IEEE Workshop on Computer Vision, Miami, Florida, November 30 - December 2, 1987.

Invited Speaker

- Invited speaker at the Optical Society Meeting in Orlando, December 1981.
- Invited speaker at Data Processing Management Association Regional Conference, Allentown, PA, 13 May 1983, on "Machine Recognition of Shapes from Vision and Touch".
- Invited speaker at The 1983 NYU Symposium on Artificial Intelligence for Business, New York University, 18-20 May 1983 on "Integrating Vision and Touch for Robotics Applications."
- Invited speaker at Seminar and Workshop on Sensors for Robotics and Flexible Automation, University of Rhode Island, Kingston, RI, 8-9 June 1983 on "Shape From Touch".
- Invited speaker, Distinguished Lecturer Series, University of Minnesota, Spring 1986, Computer Science. "Active Perception vs Passive Perception", and "Integration of Vision and Touch for Recognition Purposes".
- Invited speaker, JPL/NASA Space Telerobotics Workshop, "Object Apprehension Using Vision and Touch", Pasadena, California, 1987.
- Invited speaker, AI '87 Japan Conference. "Active Perception", pp. 549-554 .
- Invited speaker, Processing of Somatosensory Information in Biological and Artificial Systems, American Academy of Arts & Sciences, MIT March 27-28, 1989.
- Invited speaker, Sensor Fusion II: Human and Machine Strategies, SPIE, Advances in Intelligent Robotic Systems Symposium, November 6-8, 1989.

Invited Participant

- Invited participant, Research Initiation Grant Program Panel Review, National Science Foundation, March 8-9, 1983.
- Invited Participant, Congressional Office of Technology Assessment Workshop, Committee on Appropriations, United States Senate March 18-19, 1984.
- Invited participant, Engineering Equipment Awards Panel, National Science Foundation, March 26, 1986.
- Invited participant, NATO Advanced Research Workshop on "Robots and Biological Systems", Il Ciocco, Tuscany, Italy, June 26 -30, 1989.
- Invited participant, NATO Advance Study Institute (ASI) on Active Perception and Vision, July 16-19, 1989, Maratea, Italy.
- Invite participant, NATO Closing Workshop - Sensory Systems for Robotic Control, October 30 - November 3, 1989, Il Ciocco, Tuscany, Italy.

Other Activities

- Organizer of an NSF-Sponsored Workshop on the Representation of Three-Dimensional Objects, University of Pennsylvania, May 1-2, 1979.

- Member of the organizing committee of the Int. Medical Image Processing Conference, Berlin, October 1982.

- Organized the NSF sponsored Joint United States-France Second Workshop on Selected Topics in Robotics, 7-9 November 1984, University of Pennsylvania, Philadelphia, PA.

- Consultant, Advisory Committee, National Science Foundation, May 1, 1985 to April 4, 1986.

- Member of Program Committee, IJCAI '85, 18-23 August 1985, Los Angeles, CA.

- Panel Member, Panel for Manufacturing Engineering, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, 1986 - 1989.

- Member, Advisory Committee for Design, Manufacturing, and Computer-Integrated Engineering for the National Science Foundation, January 1987 - December 1989.

- Program Committee Member, Topical Meeting on Image Understanding and Machine Vision, June 12-14, 1989, Cape Cod, Massachusetts.

- Member, Advisory Committee for the CISE Office of Cross-Disciplinary Activities (CDA), 1989.

- Panel Member, National Defense Science and Engineering Graduate Fellowship Program Evaluation Panel, March, 1989.

Related work of chief investigator

Most of Solina's work in recent years was devoted to research in computer vision. The proposed research is a continuation of his doctoral research. References to this work are listed in his bibliography and in the references section of the project description.

The role of the proposed research in international and domestic frame

Computer vision is an interdisciplinary research area where robotics, artificial intelligence and cognitive science meet. A new generation of autonomous, flexible robots cannot exist without visual capabilities. Modern manufacturing employs computer vision techniques for assembly tasks and qualitiy inspection. Intelligent interpretation of images can be employed also in several other fields. Computer vision is at the same time a valuable experimental field for artificial intelligence and cognitive science theories since understanding human vision as one of the central cognitive processes is far from beeing completely understood. Despite this urgent need of automatic interpretation of images, basic issues in computer vision are still open and in order to advance all kinds of computer vision applications basic research must be funded. Basic research in computer vision is funded by private industry in all highly developed countries as well as by funding agencies in the United States (NSF, DARPA) and in Europe where computer vision is one of the areas funded by joint programs of the European Community.

To catch up with high techology in manufacturing, Slovenia must support their own researchers in computer vision.

The most important references in relation to the proposed work

are given in the references section of the project description.

Project description

Background

One of the major goals of computer vision is to recover descriptions of the physical world that enable locating, handling and identifying objects. Since shape information plays a crucial part in these activities, a substantial effort has been devoted to identify proper models for shape representation. Different shape reconstruction methods introduced different shape models, that is models that fit into the particular reconstruction philosophy (bottom-up, top-down or a combination of the two).

Segmentation of images into regions corresponding to single objects or their parts is one of the harder problems in computer vision. Recognition of objects would be easier for a vision system if the system knew which areas in an image correspond to single objects. Segmentation, on the other hand, would also be simpler if the identity of objects in the scene and hence their shape could be found beforehand. It is not obvious which problem should be tackled first. Model-based object recognition systems using feature indexing, which have the advantage of knowing the exact models of objects in the scene, try to identify these objects on the basis of some very specific features first. These local features or combinations of them can be used either to instantiate an object model from a data base or for further aggregation into shape models of larger granularity. We are interested in problems when no apriori known objects are given aside from generic models that encompass a large set of all possible part shapes—our vocabulary for describing the scene. We believe that in such cases the solution for segmentation might well be to do it *simultaneously*—to recover such parts in the images that can be described with a selected part shape vocabulary[6].

The close relation of shape recovery and segmentation is reflected in numerous vision systems where a clear distinction between segmentation, shape recovery and model instantiation is difficult to establish. Most approaches to segmentation in computer vision are based on using local image information, in the form of low level image models such as edges, surface patches and surface normals. Segmentation methods can be divided into boundary and region based methods. Boundary methods try to find significant changes that separate regions in images, while region based methods look for similarity which indicates elements that belong together. When 3-D data is available, surface normals or surface discontinuities (C_0 and C_1) are a commonly used local features. Partitioning then involves thresholding using histogram analysis or clustering in multidimensional space when several properties are used simultaneously. Since this features are very local, noise and missing information makes these segmentation methods unreliable. The problem can be partially alleviated by using coherence measures in a somewhat larger neighborhood. Examples are edge tracking and region growing and using consistency criteria for merging and splitting. Fitting of planar or higher order surface patches in a local neighborhood is a popular method to assure local consistency in range maps. Some of these methods derive the initial boundaries of local surface patches from edges and significant changes in surfaces expressed in terms of differential geometry or discontinuities of surface depth and surface normals. The resulting segmentation is often *arbitrary,* even if the similar neighboring surface patches are later merged, which is especially true for nonpolyhedral objects. This is because merging or growing of such small surface regions essentially still relies on local information. If such local segmentation methods are made sensitive enough to detect subtle changes in first or second derivatives in order to find part boundaries, they become susceptible to noise and details that are not relevant for the targeted level of representation. Such noise problems can sometimes be handled by following up events in a sequence of images at multiple resolutions.

Much work has been done recently on the problem of reconstructing piecewise-smooth surfaces in one or more dimensions [9,19] which is posed as an optimization problem. In all these approaches the data is weighted uniformly which means that the algorithms do not possess the capabilities to adapt to different conditions in different parts of the image. The global measure, provided by the energy function, is not able to tell which parts of the image are well described in terms of the underlying models and which are not. Also it is difficult to see how these approaches could be extended to subsequent stages of the vision problem without using models with fewer degrees of freedom.

Human visual perception has a remarkable capacity to grasp the overall structure of images. We can easily group the relevant features together and find parts without the need to actually recognize them. The systematic study of this perceptual organization phenomenon was first undertaken by the Gestalt school in psychology. Recently, psychological experiments have shown the particular salience of parts and part configuration as the natural bridge connecting perception (appearance) of objects, behavior (activity) toward them and in turn communication about them (naming) [23]. This *special relevance of parts* is due to their level of representation which reflects the natural breaks in the structure of the world. Research in clinical neurology has shown that the human visual system consists of mutually dissociable functions, such as visual acuity, visual shape discrimination, location and color perception [24]. Of special importance to our work is the probable dissociation between visual acuity and shape discrimination on one hand and between shape description and recognition on the other hand. The conjecture hence is that perceptual categorization stage in human vision can aggregate low level features into larger entities or achieve segmentation without semantic knowledge. Investigating models that would play a similar role in computer vision is hence justified.

There were several attempts to define parts as perceived by human vision in mathematical terms. A review is given in [6]. The application of these partitioning rules on real scenes, however, is difficult because of imperfections in low-level shape descriptions. Since part boundaries are defined in terms of differential geometry, the objects in the scene must be described with smooth surfaces so that second partial derivatives can be computed. Normally, edges and other sharp discontinuities must be smoothed out so that differentiation can be done. As an alternative source of information for finding parts contours and occluding contours have been considered. Asada and Brady [2] used a set of images at different scales for segmenting 2-D contours. A 2-D contour is, however, still a locally based shape information and segmentation based solely on it cannot always be consistent. Psychological experiments have also shown that a reasonable amount of noise on occluding contours does not interfere with human capability of recognition [8]. Illusory contours, a well known phenomena in perception, also cannot be explained purely in terms of local image structure.

All local segmentation methods, used so far in computer vision, based whether on surfaces or on contours, have problems with arbitrary segmentation. The reason seems to be that an essentially local piece of information cannot decide on the shape of the whole part if the concept of the whole part as such is not defined.

The problem of using part boundaries to define the shape of parts can be circumvented by directly defining a family of all possible part shapes. Biederman [8] argued that human perception uses a set of primitive building blocks which can describe the wealth of different shapes by combining them like phonemes in a language. Perceptual grouping is another way to extract the relevant low level image features and filter out the noise in order to reduce the search space when model matching is performed [15,11]. But the predictive power of generic models is not used to its full potential when only rules for combining low level models into larger ones are used. If the higher level generic models are well defined, one can attempt to find them in a more direct way. Search can be made more efficient if the objective can be defined in purely mathematical terms.

In our previous work the above philosophy led to the following two approaches to shape recovery and segmentation.

Volumetric part-level recovery

Pentland [17] proposed the use of superquadric models combined with global deformations as a set of primitives which could be recovered directly from images. Pentland's idea to analytically solve all independent superquadric parameters did not prove to be practical. We formulated the recovery of deformed superquadric models from range data as a least-squares minimization of a fitting function [22,21].

The recovery method can be envisioned as an interaction of intrinsic and extrinsic forces, where the intrinsic forces are the internal properties of the model, governing the arrangement of its parameters and through them its potential shape. The extrinsic forces are the image properties that influence the shape options allowed by the internal constraints. Since only a few model parameters are needed to describe a large number of image points, the model recovery problem is overconstrained.

This part-level recovery concept extends to segmentation as a problem of finding a set of part-level models that best described a scene. But any serial manner of segmentation (recovery of one part at a time [20] or partial segmentation followed by model fitting [18]) were unreliable because they cannot exploit the physical coherence of objects. If a data point does not belong to one part, it has to belong to another one. Hence shape recovery of neighboring parts should influence each other. As we argued before [6] a new method that solved shape recovery and segmentation in paralel was necessary.

Segmentation as the search for the best description in terms of primitives

We view the segmentation process as a data reduction mechanism that requantizes the sensory measurements into some predefined primitive elements which encompass the available knowledge. This enables us to infer a symbolic description of the world. Most commonly, segmentation is viewed as a local to global aggregation problem with various similarity criteria employed to achieve a coherent global description [7]. Indeed, this global description is most usefully achieved in terms of global primitives that are easy to extract and are useful for the later processing. This can be accomplished in two ways: one is to actively use the global model as the individual primitives are being developed, in essence recovering the model as aggregation proceeds. The other way is to use a local coherence measure to first classify the data and then use the fitting technique to recover the model. The latter approach, though not limited by the global model at the aggregation stage, essentially isolates the segmentation and the representation stages, with the result that the final description might not correspond to the global model since it played no part in the segmentation process. Besides, the outliers in the data set resulting from misclassification, and the sensitivity of the methods for model estimation may lead to disastrous results [10]. As mentioned before, a desirable approach is to use both the local coherence measure and the global model to guide the segmentation, corroborating the notion that the problems of segmentation and representation are not separable [6].

In [14] we define segmentation as partitioning the images (range or reflectance) into primitive models by *searching* for the models as they are developed everywhere in the image, such that the description is best in terms of global shape and error. By searching we mean fitting and selecting only those models that best describe the underlying data using the criterion function which takes into account the number of points that are described by a particular model, its goodness-of-fit, and the structural complexity of the model. Our method performs data aggregation via model recovery in terms of variable-order (up to second-order) bi-variate patches using iterative regression. Model recovery starts simultaneously and independently at all the regions found to be globally coherent in the initial neighborhood (seed regions). All the recovered models are potential candidates for the final description. To make the method computationally feasible, it is necessary to monitor region growing and discard superfluous regions even before they are fully grown. The major novelty of this approach is in combining model extraction and model selection in a dynamic way, such that only the "best" models are allowed to develop further. Perhaps the closest in spirit to our approach to model selection is the one used by Pentland [18].

Detailed description of the proposed work

We believe that the segmentation schema that we presented in [14] is a tool that will prove useful in many tasks of early vision. We described two procedures where it is clearly shown that the whole is greater than the sum of its parts (synergism). The iterative approach combining data classification and model fitting shows that segmentation and modeling are not two independent procedures but have to be integrated. The procedure which dynamically combines model recovery with model selection proves to be much more efficient than applying the modules one after another.

Another important conclusion that we could draw from our work is that reliable segmentation can only be achieved by considering many competitive solutions and choosing those which reveal some kind of structure in terms of underlying models. Initial local estimates, no matter how good they are, do not necessarily lead to a good result, and more global information is needed. Optimization that is performed on the level of primitives rather than on a pixel level not only improves the performance enormously in terms of computational complexity but also gives more reliable results.

The primitives we use in segmentation do not explicitly contain information about the boundaries of the segmented data. This is advantageous, especially in the case of occlusion, but requires a secondary process to determine the actual boundaries. Some topological models that could be incorporated into the scheme could help. Knowledge about structure can be represented for example by part to part constraints, such as how parts can touch and whether they can interpenetrate each other. A mathematically concise way of describing such constraints, including external constraints such as gravity, is in terms of energy [25]. Such constraints might be incorporated into the described recovery method since they would only add additional terms into the functional that has to be minimized. A parallel scheme where several part recovery processes *cooperate* in the image simultaneously is essential. The role of recursive decomposition, however, when smaller parts are added to larger ones only if scale or attention is focused upon them is not to be neglected.

Another interesting challenge would be to use the proposed schema as a framework for combining different sources of information. There are two places where we see that the integration of the information could take place. The first one is at the time of decision making in the iterative regression procedure and the second one at the phase of selecting optimal descriptions where different modules could influence one another through the objective function. There are color models that we introduced [3,4] that could serve as a basis for physical segmentation (material properties of surfaces). For handling of outdoor scenes inclusion of texture models is essential. Another challenge is to combine surface and volumetric models (for example superquadric models) to achieve the most compact possible shape representation of a given scene.

An important, implicit feature of our schema is that it automatically selects the *domain of applicability*, which means that it models only the data that can be expressed in terms of predefined models that we use so far. For textured regions (relative to the scale determined by the size of seed region), the schema that we describe is insufficient since we do not include any texture models. These regions are now left out in processing, since no seeds are placed there. They can be further analyzed in the same paradigm, but using different models. Small regions which have a size that is insufficient to provide enough of information for a reliable estimate can be analyzed on a different scale after new information is acquired or using a multiresolution filtering scheme such as wavelet decomposition [16]. By applying the same principles to other problems in low-level vision we want to show that it performs well in cases of noisy and incomplete information.

In parallel to the work on segmentation we want to investigate new error of fit measures for recovery of 3-D superquadric models from information sources other than 3-D points. We made some initial tests in using surface normal data along with 3-D points for superquadric recovery [5]. Using more then one shape cue can improve the shape recovery of part models which are at the same time a convenient way of integrating information from different cues. We want to find out if 3-D superquadric models could be recovered from 2-D contours (up to a scaling factor) with analytical methods. Human perception is very good at interpreting contours and we believe that the built-in parametrization of superquadrics can provide enough constraints to the recovery problem so that unique or at most two solutions would result (i.e. two competing intepretations of the Necker cube). We would like to emphasize the importance of working with 3-D models and making 3-D interpretations as early as possible for part-level shape description. Any 2-D stimulus pattern tends to be seen in such a way that the resulting 3-D structure is as simple as the given conditions permit [1]. For example, a pattern will appear three-dimensional when it can be seen as the projection of three-dimensional situation which is structurally simpler than the two-dimensional pattern. Skewed symmetry as a manifestation of this principle was investigated in computer vision [13]. Using 3-D superquadric models for segmentation and recovery and not only their 2-D projections as Pentland [18] does in his part-level segmentation approach is in our opinion essential to recover the simplest interpretation.

Between the problem of working with 2-D contours only and having accurate 3-D positions of points is a whole range of situations where the depth information is less accurate than the x-y

position of contours in the image plane. This is actually what human perception has to content with. Depth information is often more qualitative then quantitative in the sense that we have the information about the relative distances of points, for example, which points are closer or further away from the observer. This is normally sufficient to select the correct interpretation out of several possible interpretations of 2-D contour information alone. The situation in computer vision is very much the same. Due to the imaging sensors one normally has higher resolution in image plane then in the z (depth) direction. A way of incorporating this inherent asymmetry of position uncertainty into superquadric model recovery must be found. We want to find a shape segmentation and recovery procedure that could deal with the whole range of possibilities, from having 2-D contours only, shading, color, all the way up to accurate depth information in all image points. Insights from a general framework for information fusion from different sensors and for sensor modeling [12] will be used.

Expected results

We hope to contribute to the solution of the following problems:

- solve segmentation **and** shape description at the same time,
- use of generic geometrical models and models describing physical phenomena (shape, texture, color),
- combine different kinds of models applicable to different sources of information into a coherent model of the world,
- support tasks such as scene description, object recognition, obstacle avoidance and visual navigation.

We believe that the assumption that any processing stage in a vision system gets perfect, error-free data from a previous stage is highly misleading and results in limited and unreliable systems. Hence all our algorithms should NOT rely on high resolution, noise-free and in any way perfect images.

We intend to work with images of different scenes, man-made (polyhedra, smooth surfaces), as well as natural scenes (texture, vegetation, uncontrollable illumination).

0.0.1 Time table

First year

Set up the laboratory (hardware and software). Recovery of superquadrics from information sources other then range data and use volumetric models in the paralel segmentation scheme [14]. Initiate collaboration with other laboratories.

Organize a vision session at the **Melecon'91** conference.

Second year

Aleš Leonardis, currently on leave in the GRASP Laboratory, is returning to Ljubljana. Work on integration of different models for segmentation and shape recovery.

Third year

Test the algorithms on different kinds of scenes and extend the models to motion analysis.

Plan a computer vision workshop in Slovenia. Possible topic is shape description and reconstruction.

Visitors

Beside establishing regular collaboration it is very important to have a regular flow of visitors in our laboratory. In this way our work gets better known and we can learn first-hand from our visitors. Such personal contacts are especially important if we want to compete later on for projects in different European research programs.

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Facilities

Office space

A new Laboratory for Computer Vision opened at the Faculty of Electrical Engineering and Computer Science, University of Ljubljana. We have about $20m^2$ of floor space. We anticipate to get some more space shortly.

Equipment

In the Laboratory we have so far one color *HP X-terminal* connected through ethernet to the school's central computing facility which is a network of HP machines running UNIX.

We have received recently an equipment grant ($40.000) from the Slovenian Ministry of Research and Technology. On order is:

- one black & white X-terminal,
- two *Macintosh II fx* computers running *Apple Unix* and fully equiped for gray level and color image processing (digitizer boards, monitors).
- one laser printer,
- a gateway to connect the above equipment to the school's computer network.

We expect that the above equipment will be installed in the Laboratory for Computer Vision in the first quarter of 1991.

Electronic mail connection with the rest of the world is also available.

Software

Most but not all of the software that we need in our work is custom built. It has to be written by researchers themselves. We exchange software with other researchers.

Other direct costs

expandable materials, supplies, publication costs, conference registration

Budget

This is a three year project proposal. The budget outline below is *only for the first year.* The budget for the next two years should be on the same level.

Workhours

550 hours (principal investigator),
stipends for two graduate students.

Travel

Five visits to international conferences (with presentation of papers) for all participants on the project $5000.00,
Visit of our partner at University of Pennsylvania $2500.00

Consultant services

Per diem costs for our visitors in Ljubljana $2000.00

Equipment

- CCD camera $1200.00
- lens for CCD camero (manual controls) $200.00,
- lens for CCD camero (motorized controls) $1500.00,
- videorecorder with dual standard (PAL and NTSC) $3000.00,
- Data Translation QuickCapture digitazer board $3000.00,
- small equipment (tripod, optical filters) $300.00,
- books $1000.00,
- *Mathematica* software for Macintosh II $900.00

Supplies

- copying, diskettes, cartdriges, film, etc. $2000.00,

Total (without work hours)

$ 22600.00

Time plan

is given in the project description. Start of project: January 1991.

Suggested reviewers

- Prof. dr. Peter Allen
  Columbia University
  Department of Computer Science
  450 Computer Science Building
  New York, N.Y. 10027
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  tel. (212) 854-8186

- Prof. dr. Walter Kropatsch
  Technische Universität Wien
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  Abteilung für Mustererkennung und Bildverarbeitung
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- Prof. dr. Saša Divjak
  Univerza v Ljubljani
  Fakulteta za elektrotehniko in računalništvo
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Rekonstrukcija oblik s pomočjo parametričnih modelov

Predlog projekta za
Slovensko ministrstvo za raziskovalno dejavnost in tehnologijo

Franc Solina
Univerza v Ljubljani
Fakulteta za elektrotehniko in računalništvo
Tržaška 25, 61001 Ljubljana

12. november, 1990

Vodja projekta:
Doc. dr. Franc Solina

Dekan FER:
Prof. dr. Baldomir Zajc

Vodja projekta

Doc. dr. Franc Solina, dipl. ing.

Mladi raziskovalci

Aleš Jaklič, dipl. ing.
(Študent podiplomskega študija elektrotehnike na Univerzi v Ljubljani, na izpopolnjevanju na University of Pennsylvania od junija do decembra 1990.)

Aleš Leonardis, dipl. ing.
(Študent podiplomskega študija elektrotehnike na Univerzi v Ljubljani, na izpopolnjevanju na University of Pennsylvania od septembra 1988 do maja 1991.)

Število novih mladih raziskovalcev na projektu

Dva.

Tuji raziskovalci

Prof. Dr. Ruzena Bajcsy, Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia, PA 19104, USA.

Franc Solina in Ruzena Bajcsy sta prijavila skupni projekt National Science Foundation preko Jugoslovansko-Ameriškega Joint Boarda. Naslov projekta: *Image Segmentation with Parametric Part Models*

Trajanje projekta

Tri leta.

Franc Solina—dokazila o kvalificiranosti

Izobrazba:

1987 University of Pennsylvania, Philadelphia, Pennsylvania, USA
Doktorat iz računalništva

1982 Univerza v Ljubljani
magisterij iz elektrotehnike

1979 Univerza v Ljubljani
diploma iz elektrotehnike

Izkušnje:

Sept. 1988 – *Docent*, Univerza v Ljubljani
Fakulteta za elektrotehniko in računalništvo. Predavanja: Zaznavanje in umetna inteligenca, Koncepti za modeliranje vizualnih informacij (podiplom. predmet), Načrtovanje in vodenje programskih projektov, Načrtovanje in vodenje projektov, Uvod v računalništvo (kemija in tekstilna tehnologija).

1983–1988 *Doktorski študij in podoktorska specializacija*, University of Pennsylvania
Raziskovanje na področju računalniškega vida v General Robotics and Active Sensory Perception Laboratory.

1979–1982 *Stažist*, Univerza v Ljubljani.

Osebni podatki:
Rojen 31. julija, 1955 v Celju.

Objave v mednarodnih revijah

[1] Franc Solina and Ruzena Bajcsy. Recovery of mail piece shape from range images using 3-D deformable models. *International Journal of Research & Engineering, Postal Applications*, Inaugural Issue:125–131, 1989.

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Vabljena predavanja

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Recovery of deformable part models—or how to model bananas and other assorted fruits, 41st Annual Conference Society for Imaging Science and Technology (SPSE) Arlington, VA, 1988.

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Objave v konferenčnih zbornikih:

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Doktorat: Tatjana Zrimec,
Diplome: Andreja Balon, Georg Pollak, Matej Mlakar,
Podiplomski študij: Aleš Jaklič (mladi raziskovalec), Matej Mlakar, Valentina Filova.

Članstvo v mednarodnih strokovnih združenjih

- American Association for Artificial Intelligence,
- Institute of Electrical and Electronics Engineers,
- International Association for Pattern Recognition.

Sodelovanje pri projektih

- Kot stažist sodeloval pri številnih raziskovalnih nalogah za raziskovalno skupnost kot stažist na Univerzi v Ljubljani,
- Na University of Pennsylvania delal na projektu za ameriško pošto (avtomatično sortiranje paketnih pošiljk).
- Sodeloval in predstavljal delo naše skupine na DARPA Image Understanding/Strategic Computing review meetings (Autonomous Land Vehicle Project).

Sodelovanje z raziskovalnimi skupinami v tujini

- Tekoče sodelovanje z Ruzeno Bajcsy, direktorjem GRASP Laboratorija na University of Pennsylvania. Skupaj smo predložili triletni predlog NSF preko Jugoslovansko- Ameriškega odbora.
- redni kontakti in izmenjava raziskovalnih rezultatov s številnimi raziskovalci v ZDA in Evropi.
- računalniški programi, ki sem jih razvil v toku mojega doktorskega dela uporabljajo številne raziskovalne skupine, med drugim tudi skupina, ki dela na Mars Rover projektu, na Carnegie Mellon University. Z njim modelirajo objekte (kamne), ki jih robotsko vozilo namerava pobrati z mehanično roko.

Nagrade in priznanja

- Nagrada sklada Borisa Kidriča (v skupini) 1982,
- Fulbrightova potovalna štipendija 1983,
- Štipendija International Research and Exchange Board za raziskovanje 1983/84,
- Morris and Dorothy Rubinoff nagrada 1988. Podeljuje se najboljšemu doktoratu iz računalništva v preteklem akademskem letu na University of Pennsylvania.

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Izobrazba

1957	Slovak Technical University	M.S.E.E.
1967	Slovak Technical University	Ph.D.
1972	Stanford University	Ph.D.

Strokovne izkušnje

1957-1962	Research engineer, Electro-acoustic Department, Tesla, Bratislava, Czechoslovakia.
1962-1964	Maintenance engineer, (for computer URAL 2), Computation Center, Slovak Technical University, Bratislava, Czechoslovakia.

Pedagoško delo in raziskovalne izkušnje

1956-1957	Instructor, Department of Mathematics, Slovak Technical University, Bratislava, Czechoslovakia.
1964-1967	Assistant Professor, Department of Computer Science, Slovak Technical University, Bratislava, Czechoslovakia.
1967-1968	Research Assistant, Artificial Intelligence Project, Stanford University, Stanford, California.
1968-1969	Teaching Assistant, Department of Computer Science, Stanford University, Stanford, California.
1972-1977	Assistant Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia.
1977-1984	Associate Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia.
1984-	Professor, Department of Computer and Information Science, University of Pennsylvania, Philadelphia.
1985-	Chair, Department of Computer and Information Science, School of Engineering and Applied Science, University of Pennsylvania

Priznanja

- Research Fellowship, Penza, Soviet Union, October 1962–January 1963.
- Graduate Fellowship for study at Stanford University, October 1967–January 1972.

- Research Fellowship Pattern Recognition Group, CERN, Geneva, January–May 1975. (Because of my immigration status, I was not able to accept it at that time).
- Visiting scientist at INRIA-FRANCE, January–June 1979.
- Visiting Professor, Datalogisk Institut of the University of Copenhagen, April 15–June 30, 1984.
- Visiting Professor, Centro "E. Piaggio", University of Pisa, Pisa, Italy, March 1988.
- Visiting Professor, Datalogisk Institut of the University of Copenhagen, August 1988.
- Forsythe Lecturer, Department of Computer Science, Stanford University, February 1989.

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4. "Identification of the Effect of Maintenance on the Reliability of Technical Systems", *Elektrotechnicky Casopis*, 19, 265-274, 1968 (In Czechoslovakia).
5. "Computer Identification of Visual Surfaces", *Computer Graphics and Image Processing*, 113-130, February 1973.
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7. "Computer Recognition of Roads from Satellite Pictures", *IEEE Transactions on Systems, Machines and Cybernetics*, September 1976 (Co-author: M. Tavakoli).
8. "Monocular Depth Cues–A Computer Model", *Computer Graphics and Image Processing*, 52-67, May 1976 (Co-author: L. I. Lieberman).
9. "A Structured World Model in Flexible Recognition of 2-D Patterns", *Pattern Recognition*,**9**, No. 1, January 1977.
10. "Three-Dimensional Representations for Computer Graphics and Computer Vision", *Computer Graphics*, **12**, No. 3, August 1978 (Co-author: N. Badler).
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Objave v konferenčnih zbornikih

Več kot 70 objav v mednarodnih konferenčnih zbornikih.

Članstvo v uredniških odborih mednarodnih strokovnih revij

- Co-editor of special issue of *Computer Vision, Graphics, and Image Processing*, 1980.
- Associate Editor of *Trans. of IEEE on Pattern Analysis and Machine Intelligence*, since 1981.
- Editor of the *Newsletter of the International Association for Pattern Recognition* 1981-1984.
- Associate Editor of the *Computer Graphics and Image Processing Journal* since 1983.
- Associate Editor of the *Pattern Recognition Letters* since 1983.
- Associate Editor of *Journal of Robotic Systems* since 1983.
- Associate Editor of *Journal of Computer Vision* since 1986.
- Area Editor of *CVGIP: Image Understanding* since 1989.

Predsedovanje konferenc

- Co-chairman of PRIP–Chicago, 1979.
- Publicity chairman of the International Pattern Recognition Conference, 1980.
- Session chairman on the International Pattern Recognition Conference, Munich, 1980 and 1982.
- Invited session chair, “Edge Detection”, IEEE Workshop on Computer Vision, Miami, Florida, November 30 - December 2, 1987.
- Chairman, Review Committee for Undergraduate Programs in Computer Science, Loyola University, March 1988

- Chairman, Review Committee for Undergraduate Programs in Computer Science, Tulane University, March 1988
- Co-Chair, Second International Conference Computer Vision, December 5-8, Tarpon Springs, Florida, 1988.
- Invited session chair, "Edge Detection," IEEE Workshop on Computer Vision, Miami, Florida, November 30 - December 2, 1987.

Vabljena predavanja

- Invited speaker at the Optical Society Meeting in Orlando, December 1981.
- Invited speaker at Data Processing Management Association Regional Conference, Allentown, PA, 13 May 1983, on "Machine Recognition of Shapes from Vision and Touch".
- Invited speaker at The 1983 NYU Symposium on Artificial Intelligence for Business, New York University, 18-20 May 1983 on "Integrating Vision and Touch for Robotics Applications."
- Invited speaker at Seminar and Workshop on Sensors for Robotics and Flexible Automation, University of Rhode Island, Kingston, RI, 8-9 June 1983 on "Shape From Touch".
- Invited speaker, Distinguished Lecturer Series, University of Minnesota, Spring 1986, Computer Science. "Active Perception vs Passive Perception", and "Integration of Vision and Touch for Recognition Purposes".
- Invited speaker, JPL/NASA Space Telerobotics Workshop, "Object Apprehension Using Vision and Touch", Pasadena, California, 1987.
- Invited speaker, AI '87 Japan Conference. "Active Perception", pp. 549-554 .
- Invited speaker, Processing of Somatosensory Information in Biological and Artificial Systems, American Academy of Arts & Sciences, MIT March 27-28, 1989.
- Invited speaker, Sensor Fusion II: Human and Machine Strategies, SPIE, Advances in Intelligent Robotic Systems Symposium, November 6-8, 1989.

Vabljeni udeleženec

- Invited participant, Research Initiation Grant Program Panel Review, National Science Foundation, March 8-9, 1983.
- Invited Participant, Congressional Office of Technology Assessment Workshop, Committee on Appropriations, United States Senate March 18-19, 1984.
- Invited participant, Engineering Equipment Awards Panel, National Science Foundation, March 26, 1986.
- Invited participant, NATO Advanced Research Workshop on "Robots and Biological Systems", Il Ciocco, Tuscany, Italy, June 26 -30, 1989.
- Invited participant, NATO Advance Study Institute (ASI) on Active Perception and Vision, July 16-19, 1989, Maratea, Italy.
- Invite participant, NATO Closing Workshop - Sensory Systems for Robotic Control, October 30 - November 3, 1989, Il Ciocco, Tuscany, Italy.

Druge aktivnosti

- Organizer of an NSF-Sponsored Workshop on the Representation of Three-Dimensional Objects, University of Pennsylvania, May 1-2, 1979.

- Member of the organizing committee of the Int. Medical Image Processing Conference, Berlin, October 1982.
- Organized the NSF sponsored Joint United States-France Second Workshop on Selected Topics in Robotics, 7-9 November 1984, University of Pennsylvania, Philadelphia, PA.
- Consultant, Advisory Committee, National Science Foundation, May 1, 1985 to April 4, 1986.
- Member of Program Committee, IJCAI '85, 18-23 August 1985, Los Angeles, CA.
- Panel Member, Panel for Manufacturing Engineering, Commission on Physical Sciences, Mathematics, and Resources, National Research Council, 1986 - 1989.
- Member, Advisory Committee for Design, Manufacturing, and Computer-Integrated Engineering for the National Science Foundation, January 1987 - December 1989.
- Program Committee Member, Topical Meeting on Image Understanding and Machine Vision, June 12-14, 1989, Cape Cod, Massachusetts.
- Member, Advisory Committee for the CISE Office of Cross-Disciplinary Activities (CDA), 1989.
- Panel Member, National Defense Science and Engineering Graduate Fellowship Program Evaluation Panel, March, 1989.

Opis sorodne dejavnosti vodje projekta

Večina raziskovalnega dela Soline v zadnjih letih je na področju računalniškega vida. Ta projekt je nadaljevanje njegovih doktorskih raziskav. Objave rezultatov so naštete v njegovih kvalifikacijah in v literaturi znanstvenega opisa projekta.

Mesto, ki ga ima raziskava v mednarodnem in domačem merilu

Računalniški vid je interdisciplinarno raziskovalno področje, kjer se stikajo robotika, umetna inteligenca in kognitivna znanost. Nova generacija avtonomnih in fleksibilnih robotov ne more obstajati brez zmožnosti vidnega zaznavanja. Moderna proizvodnja uporablja računalniški vid pri sestavljanju in za kontrolo kvalitete. Inteligentno interpretacijo slik se uporablja tudi na številnih drugih področjih. Računalniški vid je obenem dragoceno eksperimentalno področje za umetno inteligenco in kognitivno znanost, saj tudi razumevanje človeškega vida kot enega osrednjih človenških kognitivnih procesov še zdaleč ni popolno. Kljub veliki potrebi po avtomatični interpretaciji slik, pa so v računalniškem vidu odprta še številna bazična vprašanja. Do bi omogočili boljše rezultate pri številnih praktičnih aplikacijah računalniškega vida je potrebno podpirati osnovne raziskave na tem področju. Bazične raziskvave računalniškega vida podpira v vseh razvitih državah sveta privatna industrija in državne agencije (NSF, DARPA v ZDA, ESPRIT v Evropi).

Da bi Slovenija lahko držala korak z visoko tehnologijo v proizvodnji mora skrbeti tudi za ustrezno domačo raven računalniškega vida.

Najpomembnejše reference tujih avtorjev, ki obravnavajo predlagano tematiko

so navedene v literaturi znanstvene vsebine projekta.

Znanstvena vsebina projekta

Osnove

Ena od osnovnih ciljev računalniškega vida je rekonstrukcija takega opisa fizičnega sveta, ki omogoča ugotavljanje položaja, rokovanje in razpoznavanje predmetov. Zato ker informacija o obliki igra važno vlogo pri vseh teh aktivnostih v računalniškem vidu iščemo primerne modele za predstavo oblike. Različne metode za rekonstrukcijo oblik so vpeljale različne modele za predstavo oblike in zato ti modeli oblike sodijo pač v v določeno metodologijo rekonstrukcije (od spodaj-navzgor, od zgoraj-navzdol ali kombinacija obeh). Segmentacija slik v take dele, ki ustrezajo posameznim predmetom ali njihovim delom je ena od težjih problemov v računalniškem vidu. Razpoznavanje predmetov bi bilo lažje, če bi vnaprej vedeli kateri deli slike ustrezajo posameznim predmetom. Segmentacija pa bi bila po drugi strani tudi lažja, če bi že vedeli kateri predmeti so upodobljeni na sliki. Nikakor ni očividno, katerega od obeh problemov je lažje najprej rešiti. Sistemi za razpoznavanje, ki delajo s pomočjo zbirke vseh možnih modelov predmetov, skušajo uganiti kateri predmeti so na sliki tako, da iščejo specifične značilnosti. Na osnovi take lokalne značilnosti, oziroma kombinacije večih takih značnic, lahko "ugibamo" kateri predmeti so na sliki. Nas pa zanimajo taki sistemi, ki ne vedo vnaprej kateri predmeti se lahko nahajajo na sliki, razen tega, da imajo splošne modele, ki lahko predstavljajo kar največjo skupino vseh možnih oblik (slovar oblik za opisovanje okolja). Menimo, da je možno segmentacijo v takih sistemih izvesti le tako, da poteka segmentacija *hkrati* z rekonstrukcijo oblik, ki jih je moč opisati z našim slovarjem oblik[6].

Ozka povezanost rekonstrukcije oblike in segmentacije se odraža v številnih sistemih računalniškega vida, kjer je pravzaprav težko potegniti jasno ločnico med segmentacijo, rekonstrukcijo oblike in izbiro modela oblike. Večina metod za segmentacijo v računalniškem vidu uporablja lokalno informacijo v sliki (robovi, zaplate, površinske normale). Segmentacijske metode lahko temeljijo na razlikah ali na podobnostih v sliki. Prve iščejo take razlike v sliki, ki razmejijo posamezna področja na sliki. Druge pa iščejo podobnosti, ki povežejo področja v smiselno celoto. Kadar imamo globinsko sliko, so površinske normale in pretrgane površine (C_0 and C_1) najbolj uporabne lokalne informacije. Razdelitev zato zahteva analizo histogramov in druge metode razpoznavanja vzorcev. Ker so te informacije le lokalne narave, je segmentacija zaradi prisotnosti šuma ali manjkajoče informacije precej nezanesljiva. Pomagamo si sicer lahko z merjenjem sovisnosti v nekoliko večji okolici. Primeri take metodologije so sledenje robov in rast regij, ki uporabljajo kriterije konsistentnosti za združevanje ali cepljenje. Prileganje površin prvega ali višjih redov na lokalne zaplate tudi zagotavlja lokalno konsistentnost v globinskih slikah. Začetne razmejitve teh zaplat so lahko robovi ali zadostne spremembe v ukrivljenosti površin (diferencialna geometrija) ali pretrgane površine. Rezultirajoča segmentacija je pogosto povsem naključna, še posebej za poljubne oblike, zato ker združevanje in ločevanje površinskih zaplat še vedno v bistvu sloni na lokalnih informacijah. Če pa te lokalne segmentacijske metode skušamo narediti bolj občutljive, da bi zaznale že majhne razlike v prvem ali celo drugem odvodu, pa postanejo preveč občutljive za motnje ali detajle, ki niso relevantni za želeni nivo rekonstrukcije. Teh problemov se lahko lotimo tudi z multiresolucijskimi tehnikami.

Precej raziskovalcev se je v zadnjem času lotilo rekonstrukcije s pomočjo majhnih površinskih zaplat v eni ali več dimenzijah[9,19]. V vseh primerih imajo podatki enako težo pri rekonstrukciji ne glede na razmere v določenem delu slike. Globalna mera podobnosti nam ne more povedati, kateri deli slike so dobro rekonstruirani, kateri pa ne. Težko je tudi razširiti te metode na kasnejše stopnje interpretacije slike, ne da bi vpeljali modele z manjšim številom prostorskih stopenj.

Človeški vid ima neverjetno sposobnost zaznavanja celotne strukture slik. Zlahka lahko grupiramo relevantne značilnosti in najdemo smiselne dele, katere pa ni nujno, da jih tudi razpoznamo. Gestaltovska šola v psihologiji je prva preučevala te fenomene. Psihologi pa so pred kratkim eksperimentalno ugotovili, da so deli in njihova konfiguracija posebno pomembni v tem smislu, ker tvorijo povezavo med izgledom predmetov (zaznavanjem) in njihovim imenovanjem (komunikacija) [23]. Ta *posebna relevantnost delov* je rezultat nivoja s katerim opisujejo svet in ki odražajo naravne delitve v strukturi sveta. Raziskave na področju klinične nevrologije so pokazale, da človeški zaznavni aparat sestoji iz večih med seboj ločljivih funkcij, kot so ostrina (ločljivost) vida, razlikovanje oblik, določanje položaja in ločevanje barv [24]. Nas še posebno zanima možna delitev ločljivosti in razlikovanja oziroma razpoznavanja oblik. Iz tega bi namreč lahko sklepali, da je možno razdeliti sliko v smiselne celote ne da bi te posamezne dele tudi razpoznali (identificirali). Zato nas zanimajo taki modeli oblik, ki bi lahko odigrali podobno vlogo v računalniškem vidu.

Bilo je že več poskusov matematične definicije oblike takih delov, ki ustrezajo človeškemu dojemanju delov. Pregled teh definicij smo podali v [6]. Praktična uporaba teh definicij pri analizi nesintetičnih slik pa je izredno težavna, saj zahtevajo uporabo diferencialne geometrije. Predmeti bi morali imeti gladke površine, ki bi dopuščale izračun parcialnih odvodov druge stopnje. Do gladkih površin lahko pridemo z glajenjem. Alternativna za iskanje delov so informacije, ki jih razberemo iz obrisov predmetov [2]. Dvo-dimenzionalni obris pa je še vedno lokalna informacija in segmentacija na osnovi lokalnih informacij ne more biti vedno pravilna. Psihološki eksperimenti pa so pokazali, da motnje in manjkajoči deli kontur ne motijo preveč človeške zmožnosti razpoznavanja [8]. Tudi navidezne obrise, znano vizualno iluzijo, ne moremo obrazložiti le z lokalno strukturo slik.

Vse lokalno temelječe segmentacijske metode v računalniškem vidu so imele do sedaj težave z naključno segmentacijo, saj neka povsem lokalna informacija ne more odločiti o globalni obliki, če ustreznega koncepta, kako celota lahko sploh izgleda, ni na voljo.

Problem iskanja obrisov posameznih delov, da bi določili obliko teh delov lahko obidemo tako, da direktno definiramo družino vseh možnih oblik delov. Biederman [8] utemeljuje, da človeška percepcija uporablja množico elementarnih delov, ki lahko bogastvo različnih oblik opiše s kombiniranjem teh elementov, podobno kot končno število fonemov lahko opiše katerikoli jezik. Perceptualno grupiranje je še eden od načinov, da iz množice lokalnih značilnosti izločimo tiste relevantne, ki so uporabne za "ugibanje" o identiteti delov oziroma predmetov [15,11]. Toda predikcijska moč generičnih modelov ni le v uporabi pravil, ki povedo katere lokalne značilnosti sodijo skupaj. Uporabna definicija generičnih modelov omogoča direktno rekonstrukcijo teh modelov.

V našem predhodnem delu smo uporabili zgoraj opisano filozofijo rekonstrukcije oblik in segmentacije. Oglejmo si glavne rezultate.

Rekonstrukcija volumetričnih modelov

Pentland [17] je prvi predlagal uporabo supereliptičnih modelov kombiniranih z globalnimi deformacijami kot slovar primitivnih oblik, ki bi se jih dalo rekonstruirati direktno iz slik. Pentland je predlagal analitično rešitev za parametre superelipsoidov, ki pa se v praksi ne da izvesti. Zato smo predlagali nov način rekonstrukcije deformiranih superelipsoidov iz globinskih slik, ki sloni na vsoti najmanjših kvadratov nove kriterijske funkcije, ki smo jo poimenovali funkcija prileganja [22,21].

Rekonstrukcijo si lahko predstavljamo kot interakcijo notranjih in zunanjih sil, kjer so notranje sile parametrizacija modela, ki določa kakšne oblike lahko model navzame. Zunanje sile pa so podatki v sliki, ki oblikujejo model v okviru dovoljene parametrizacije. Zato ker je potrebno le manjše število parametrov za predlagan model oblike, v sliki pa je veliko več informacij, je rekonstrukcija formulirana kot optimizacija—iskanje vsote najmanjših kvadratov.

Ta koncept rekonstrukcije oblik posameznih delov se lahko razširi tudi na segmentacijo, kjer je pač potrebno poiskati tisto najmanjšo množico modelov, ki najbolje "razloži" sceno. Toda serijski način segmentacije (po eden model naenkrat) [20] ali tudi delna segmentacija, ki ji sledi bolj natančna rekonstrukcija [18], se je izkazala za nezanesljivo, ker enostavno ne upošteva fizične koherence predmetov. Če nekega dela slike model ne zajema, ga mora obsegati nek drug sosednji model. Rekonstrukcija oblik sosednjih delov mora torej vplivati drug na drugega. Zato trdimo, da se mora rekonstrukcija oblike in segmentacija vršiti istočasno [6].

Segmentacija kot iskanje najboljšega opisa z osnovnimi delci

Segmentacijo razlagamo kot proces redukcije podatkov, ki razloži meritve senzorjev v obliki vnaprej določenih primitivnih elementov, ki zajemajo naše razumevanje problematike. To omogoča dojemanje sveta v simbolični obliki. Preprosto povedano, je segmentacija združevanje informacij v vedno večje celote s pomočjo kriterijev podobnosti, da bi dosegli splošen opis neke scene [7]. Splošen opis želimo imeti v obliki elementarnih delov, ki jih ni težko rekonstruirati in ki so uporabni za nadaljnje procesiranje. To lahko dosežemo na dva načina: prvi je, da modele aktivno uporabljamo med samo rekonstrukcijo, ko iščemo primerne podatke. Drugi način je, da najprej izoliramo podatke, nato pa jim priredimo naš model. S tem drugim načinom v bistvu razdelimo segmentacijo na dva ločena postopka, kjer na končni rezultat naš model pravzaprav nima velikega vpliva. Pravtako lahko kakršnekoli motnje v podatkih vodijo do povsem napačnih rezultatov [10]. Kot smo že prej omenili si zato želimo združiti problem segmentacije in predstave oblike [6].

V [14] smo segmentacijo definirali kot delitev slike na take dele, da so pripadajoči modeli, ki jih hkrati iščemo povsod v sliki, najboljši opis tako glede globalnega prileganja, kot globalne napake v celotni sliki. Z iskanjem razumemo rekonstrukcijo tistih modelov, ki najbolje opišejo sliko. Kriterijska funkcija pa vključuje prileganja modela, število točk, ki jih modelira in kompleksnost našega modela.

Naša metoda združuje podatke s pomočjo modela spremenljive stopnje kompleksnosti (površinske zaplate do drugega reda) s pomočjo iterativne regresije. Rekonstrukcija modela se povsem neodvisno začne povsod tam na sliki, kjer obstajajo dovolj veliki koherentni deli (semena). Vsi rekonstruirani modeli so potencialni kandidati za končni opis. Da bi se izognili kombinatorični eksploziji, dinamično nadzorujemo rekonstrukcijo modelov, tako da se le najboljši modeli razvijajo naprej. V tem je še najbližji način selekcioniranja, ki ga opisuje Pentland [18].

Podroben opis predlaganega dela

Menimo, da je segmentacija, ki smo jo predlagali [14], takšno orodje, ki bo uporabno še pri drugih nalogah nižjega vida. Opisali smo dve proceduri, ki kažeta, da je celota večja od vsote delov (sinergizem). Iterativni pristop, ki kombinira klasifikacijo podatkov z rekonstrukcijo modelov, jasno kaže, da segmentacija in modeliranje nista ločena postopka. Dinamična kombinacija izbiranja modelov z rekonstrukcijo modelov pa ves postopek naredi veliko bolj učinkovit in hitrejši.

Naše delo pa kaže tudi na to, da zanesljivo segmentacijo lahko dosežemo le, če upoštevamo veliko število možnih rešitev in izberemo tako rešitev, ki razkrije najbolj preprosto strukturo izraženo z izbranimi modeli. Začetni približki, ne glede na to kako dobri so, ne vodijo zanesljivo do dobrega rezultata. Potrebna je bolj globalna informacija. Optimizacija, ki jo izvedemo na ravni modelov in ne na ravni slikovnih elementov, izredno izboljša rekonstrukcijo, tako v smislu zmanjšanja kompleksnosti, kot v bolj zanesljivih rezultatih.

Primitivni elementi, ki jih uporabljamo pri segmentaciji eksplicitno ne vsebujejo informacije o mejah segmentiranih podatkov. To je pravzaprav koristno, še posebno v primeru zakrivanja. Zahteva pa dodaten proces, ki odkrije dejanske meje. Topološki modeli bi morda pomagali pri tem postavljanju meja. Informacijo o strukturi lahko predstavimo z opisom omejitev na stiku dveh delov; naprimer, ali dela lahko segata eden v drugega in podobno. Matematično koncizen način predstavljanja takih omejitev, vključno z zunanjimi omejitvami kot je gravitacija, je s pomočjo energije [25]. Take omejitve, vključene v opisane rekonstrukcijske metode, bi le prišteli k funkciji, ki jo je potrebno minimizirati. Raziskati je potrebno tudi kako bi lahko več takih procesov delovalo paralelno in kako bi vključili tako rekonstrukcijo v rekurzivno dekompozicijo, kjer bi večjim delom postopoma dodajali manjše.

Zanimiv izziv je tudi uporaba opisane sheme kot ogrodje za kombiniranje raznovrstnih vizualnih informacij. Integracija informacij bi lahko potekala na dveh mestih. Prvič je takrat, ko delamo odločitve med iterativno regresijo, drugič pa, ko izbiramo optimalen opis, ko bi razni moduli lahko vplivali drug na drugega s pomočjo nekega funkcionala. Definirali smo naprimer modele za barve [3,4], ki bi lahko služili kot osnova za fizikalno segmentacijo (materialne lastnosti površin). Za naravne scene je nujno vključiti modele za teksture. Izziv je tudi kombinacija površinskih in volumetričnih modelov, da bi dosegli čim bolj kompakten opis oblike podane scene.

Izredno važna, toda implicitna lastnost naše sheme za segmentacijo je, da avtomatično izbere domeno aplikatibilnosti, kar pomeni, da modeli predstavljajo le tiste podatke, ki se jim lahko priležejo. Deli slik, naprimer izrazito močne teksture, ki jih z našimi dosedanjimi modeli še ne moremo modelirati, so pri segmentaciji povsem izpuščeni. Zato pa jih lahko analiziramo z drugačnimi postopki. Majhne regije, ki ne dajo zadosti informacije, da bi lahko dobili zanesljivo prvo oceno, moramo analizirati pod večjo "povečavo", s tem da zberemo več informacij ali pa z uporabo multiresolucijskega filtriranja [16]. Iste principe bi radi uporabili na drugih problemih zgodnjega vida, da pokažemo, da delujejo dobro tudi v prisotnosti šuma in manjkajočih informacij.

Vzporedno z delom na segmentaciji bomo raziskovali tudi nove mere prileganja za superelipsoide pri njihovi rekonstrukciji iz drugih virov informacij. Naredili smo že nekaj začetnih eksperimentov z uporabo površinskih normal skupaj s 3-D točkami [5]. Uporaba večih virov informacij o obliki bi naredilo rekonstrukcijo superelipsoidov bolj zanesljivo. Radi bi ugotovili, če je možno rekonstruirati 3-D superelipsoide iz 2-D kontur (do faktorja povečave) zgolj z analitičnimi metodami. Človeški vid je izredno zanesljiv pri interpretaciji kontur in zato menimo, da bi parametrizacija vgrajena v superelipsoide bila zadostna omejitev pri rekonstrukciji, da bi lahko našli eno, največ dve možni rešitvi (naprimer, dve rešitvi pri Neckerjevi kocki). Radi bi tudi povdarili, da je potrebno uporabiti 3-D modele čimbolj zgodaj v interpretaciji slik, da bi lahko sklepali o 3-D obliki posameznih delov. Vsako 2-D obliko moramo interpretirati tako, da je rezultirajoči 3-D model čimbolj enostaven [1]. Tako naprimer vidimo nek vzorec kot projekcijo tridimenzionalne strukture, če je ta 3-D struktura enostavnejša kot njena 2-D projekcija. Popačeno simetrijo (skewed symmetry) kot manifestacijo tega principa so že raziskovali v okviru računalnikega vida drugi [13]. Menimo, da zato za segmentacijo in rekonstrukcijo oblike potrebno uporabiti 3-D superelipsoide, ne pa le njihove 2-D projekcije kot to dela Pentland [18].

Za rekonstrukcijo oblike smo do sedaj omenili le uporabo natančno določenih 3-D točk na površini predmetov in uporabo 2-D obrisov. To pa sta v resnici le dve skrajnosti istega problema, s katerim se pa najbolj pogosto srečamo nekje v "sredini". Normalno je, da so globinske informacije dosti manj natančne od pozicije točk v slikovni ravnini. Tudi človeški vid se mora znajti v isti situaciji. Informacija o globini je velikokrat le kvalitativna, saj lahko ocenimo le katere točke so bližje glede na druge točke. To normalno povsem zadostuje človeku, saj se človeški vid le redkokdaj pusti zavesti. Tudi senzorji v računalniškem vidu imajo večjo resolucijo v slikovni ravnini kot v smeri gledanja, ne glede na to, ali informacijo o globini izračunamo posredno (stereo tehnike in podobno) ali merimo direktno (laserski sistemi). Zato bi radi upoštevali to naravno asimetrijo tudi pri rekonstrukciji superelipsoidov, tako da bi lahko upoštevali ves razpon možnosti pri vhodnih podatkih, od golih 2-D kontur, preko dodanega senčenja, barv in teksture, ki omogočajo relativno oceno globine, pa vse do natančnih podatkov o 3-D točkah. Pri tem bomo upoštevali rezultate raziskav o združevanju (fuziji) informacij iz večih in raznovrstnih senzorjev [12].

Pričakovani rezultati

Z načrtovanim delom želimo:

- omogočiti hkratno segmentacijo in rekonstrukcijo oblike,
- uporabo splošnih geometrijskih modelov za opis fizičnih fenomenov (oblika, tekstura, barva),
- združili raznovrstne modele za različne vrste vizualnih informacij v koherenten model sveta,
- omogočiti različne cilje pri interpretaciji slik, kot so opisovanje scene, razpoznavanje predmetov, izogibanje predmetov in vizualna navigacija.

Pri našem delu nas vodi prepričanje, da se nobena stopnja procesiranja v računalniškem vidu ne more zanesti na popolne vhodne podatke, ki bi bili povsem brez šuma in napak. Predpostavka o popolnih podatkih vodi le do nestabilnih in zavajujočih rezultatov.

Delali bom s slikami iz različnih domen, od umetnih scen (polihedri, gladke površine) do naravnih (teksture, vegetacija, iluminacija, ki se je ne da kontrolirati).

Program dela

Prvo leto

Vspostaviti osnove za raziskovalno delo v Laboratoriju za računalniški vid. Razširitev sistema za rekonstrukcijo superelipsoidov na druge vrste vhodnih podatkov in uporaba volumetričnih modelov pri paralelni metodi segmentacije [14].

Organizacija sekcije za računalniški vid na **Melecon'91** konferenci v Ljubljani, na katero smo povabili številne znane raziskovalce.

Drugo leto

Integracija različnih modelov (tekstura, senčenje, barve) pri segmentaciji in rekonstrukciji oblike.

Tretje leto

Testiranje algoritmov na različnih vrstah scen. Uporaba razvitih modelov pri interpretaciji gibanja.

Organizacija mednarodnega delovnega srečanja posvečenega problematiki modeliranja in rekonstrukcije oblike v računalniškem vidu v Sloveniji.

Obiskovalci

Poleg rednega sodelovanja z našim tujim partnerjem je še posebej pomembno, da vspostavimo reden dotok tujih obiskovalcev v našem laboratoriju. Na ta način postane naše delo bolj znano, učimo pa se tudi od naših obiskovalcev. Taki osebni kontakti so še posebej pomembni, če hočemo kasneje kandidirati tudi za projekte v okviru Evropske skupnosti.

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Zmogljivosti

Prostor

Na Fakulteti za elektrotehniko in računalništvo Univerze v Ljubljani se je formiral nov Laboratorij za računalniški vid v okviru Katedre za računalništvo in informatiko. Trenutno razpolagamo z $20m^2$ prostora. Ker je laboratorij hkrati naša pisarna, upamo, da bomo v doglednem času dobili dodaten prostor.

Oprema

Trenutno je v laboratoriju le eden barvni *HP X-terminal*, ki je priključen na fakultetno računalniško mrežo (več HP računalnikov z UNIX operacijskim sistemom).

V letošnjem paketu raziskovalne opreme, pa smo od Slovenskega ministrstva za raziskovalno dejavnost in tehnologijo dobili \$40.000 za nakup opreme. Naročena je naslednja oprema:

- eden črno-beli X-terminal,

- dva *Macintosh II fx* računalnika z *Apple Unix* operacijskim sistemom, ki sta posebej opremljena za delo s slikami (barvni monitorji, vzorčevalniki slike),
- laserski tiskalnik,
- vrata za povezavo vse laboratorijske opreme na fakultetno računalniško mrežo.

Pričakujemo, da bo našteta oprema instalirana v prvih mesecih leta 1991.

Pri svojih stikih s svetom se v veliki meri poslužujemo elektronske pošte.

Programska oprema

Večina, toda ne vsa programska oprema, ki jo potrebujemo, moramo razviti sami, ali pa jo dobimo z izmenjavo z drugimi laboratoriji.

Predračun

Naš predlog raziskav je za triletni projekt. Ker navodila za izdelavo predračuna niso natančno določena in ker se pričakuje, da se bo metodologija financiranja raziskovalnega dela spremenila, se predračun nanaša le na *prvo leto*. Naše potrebe v naslednjih dveh letih bodo ostale predvidoma v enakih okvirih.

Delo

550 ur (glavni raziskovalec),
dva mlada raziskovalca.

Potovanja

Za vse udeležence na projektu skupaj 5 obiskov (s prezentacijo članka) na mednarodnih konferencah \$5000.00,
Obisk našega partnerja na University of Pennsylvania \$2500.00

Angažiranje tujih raziskovalcev (konzultacije)

Bivanje naših obiskovalcev v Ljubljani \$2000.00

Oprema

- CCD kamera \$1200.00
- objektiv za CCD kamero (ročne kontrole) \$200.00,
- objektiv za CCD kamero (motorizirane kontrole) \$1500.00,
- videorekorder z dvema standardoma slike (PAL in NTSC) \$3000.00,
- Data Translation QuickCapture kartica za digitalizacijo barvnih slik \$3000.00,
- drobna oprema (stativ, optični filtri) \$300.00,
- knjige \$1000.00,
- *Mathematica* program za Macintosh II računalnike \$900.00

Materialni stroški

- potrošni material (stroški razmnoževanja, diskete, vložki za laserski tiskalnik, filmi) \$2000.00,

Skupaj (brez dela)

\$ 22600.00

Časovni termini izvajanja projekta

so navedeni v znanstvenem opisu projekta. Začetek projekta Januar 1991.

Predlog recenzentov

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